ABSTRACT

The final thesis will deal with an immersed tunnel design of 13.37 km long based on the Flyland project, a project to expand Schiphol Airport on an artificial island (Flyland) in North Sea. Approximately 111 immersed tunnel elements will be needed to connect Flyland with an intermediate island between the Netherlands and Flyland itself, which each element consists of six segments of 20 m. In addition, the thesis will focus in the design for the deepest tunnel element (cross and longitudinal sections including the reinforcement and post-tensioning) of the project and later on remarks are given for other tunnel elements.

Based on the technical criteria mentioned in the report such as the clearance gauge, number of the traffic lanes, width of the pedestrian/inspection lanes, area for the ballast concrete, area for the interior equipment (ventilations, lightings, and signs), area of the service galleries, area to put on the GINA gasket, and area to put on the pre-stressed cables, then we come up with three tubes of 7.5 m and two service galleries of 1.35 m. The cross sections of the tunnel it self eventually has height of 11.2 m and width of 30.8 m.

The reinforcement in the tunnel element cross section will be designed in Indonesian code (SKSNI) by inserting several comparisons to NEN (Dutch Code) especially for the crack width control since there is no SKSNI crack width control parameter for the sea environment. The result shows that using the SKSNI (with steel yield stress of 400 MPa), the amount of reinforcement needed is 124 kg/m^3, which is in between the normal range of 110 – 130 kg/m^3 for the tunnel constructions in the Netherlands which normally use steel yield stress of 500 MPa. Meanwhile the density of reinforced concrete got is 24.4 kg/m^3 (the density includes the post-tensioned cables)

For the longitudinal direction, post-tensioned cables design is applied mainly to bond the segments together in one whole element during the phases from the fabrication until the end situation. Design of the maximum positive moment is achieved from the transport phase with 1.5 meter *cosinus* wave (minimum design) and the maximum negative moment is taken from the transport phase without wave

consideration (maximum design). Minimum compression stress of 0.3 MPa is given as a parameter on the total cross section of the element. Hence, the cables needed are 29 tendons of strands 19ø15[7] (FeP1860) which is distributed as follows: 11 cables in the roof and 18 cables in the floor. Eventually, total losses in the cables are calculated according to NEN 6720.

Due to the importance of flexibility needed within the segments of 20 meters, the expansion joints are fixed-in between the tunnel segments. The main purpose to this joint is to withstand the tunnel movements and make a water tight layer. The principle, details, and the incoming problem for the expansion joint subjected to Flyland project have been brought out in this report.

The element/unit joint are maintained firstly by the GINA gasket to get a temporary water seal. The GINA is then totally compressed by the horizontal water pressure after the room in between two elements is de-watered. Later on, omega seal as the main water seal will be put on. As the main water seal system, the service life time of the omega seal will be made twice of that for the tunnel itself. The details, the trial of the omega seal, and the incoming problems subjected to Flyland project are described in this report.

In between the last immersed tunnel element and the "cut and cover" tunnel, there will be a final/closure joint. A new design of the final joint is ought to be in situ constructed, then a new developed final joint is brought up in the discussion. A collar around the cast in situ tunnel is developed to have dry circumstances during constructing the closure joint of the tunnel. Moreover, improvements to a better construction and easier execution are the main objectives to the new final joint (closure joint patent: RCA-AA-99020).

The last but not the least, cost estimation is calculated to have a description all direct costs and indirect ones. However, the estimation is based on the tunnel element designed which is led to the total costs of all immersed tunnel elements.

Keywords: *immersed tunnel, element, segment, cross section, longitudinal section, reinforcement, SKSNI, NEN, post-tensioned cables, expansion joint, element/unit joint, the new final joint, cost estimation.*

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APPENDICES

LIST OF SYMBOLS, ABBREVIATIONS AND DEFINITIONS USED

β	wobble factor
γ'	effective density soil
γ_{bmax}	maximum density of ballast concrete
γ_{bmin}	minimum density of ballast concrete
γ_{cmax}	maximum density of reinforced concrete
γ_{cmin}	minimum density of reinforced concrete
γ_{ctmax}	maximum density of concrete temporary wall
γ_{ctmin}	minimum density of concrete temporary wall
γ_{sat}	density of saturated soil
γ_{t}	density of water tank
γ_{wmin}	minimum density of sea water
γ_{wmax}	maximum density of sea water
δ	wedge setting
ε'_{r}	shortened caused by shrinkage
ε'_{c}	basic shrinkage
ε'_{max}	maximum value for calculation of specific shortened due to shrinkage
ε_{u}	ultimate yield stress
λ	coefficient of neutral earth pressure
μ	friction
ρ_{min}	minimum moment reinforcement ratio
ρ_{max}	maximum moment reinforcement ratio
σ	force per area
σ'_{bo}	force of total cables per concrete area
$\sigma_{p,1000h}$	relaxation after 1000 hours
$\sigma_{p,n+\varphi}$	losses due to shrinkage and creep
σ_{po}	strength after sudden losses
$\Delta\sigma'_{el}$	elastic loss
$\Delta\sigma_{p,rel}$	relaxation loss

φ'	effective internal angle friction of soil
Ø	creep coefficient
$Ø_{max}$	maximum value for calculation of creep coefficient
$\overline{\omega}_o$	percentage of the longitudinal reinforcement
A	section area
B	the minimum total area for ballast concrete
c.t.c	distance from center to center
E'b	elasticity modulus of concrete (= Ec), Dutch term
Ec	elasticity modulus of concrete (= E'b), American term
E_p	elasticity modulus of steel
e	eccentricity
e_f	eccentricity in the floor
e_r	eccentricity in the roof
f'b	cubical characteristic compression strength of concrete
f'c	cylindrical characteristic compression strength of concrete (= f'_{ck}), American term
f'_{ck}	cylindrical characteristic compression strength of concrete (= f'c), Dutch term
fp	ultimate tension stress of post-tensioned cable
fy	yield stress of reinforced steel
H	total area of the required hollow space
h_m	the height value of two times area divided by the perimeter of the concrete
k_b	factor dependent to f'_{ck}
k_c	factor dependent to relative humidity
k_d	factor dependent to the age of the concrete and strength class
k_f	kern in the floor
k_h	factor dependent to h_m
k_p	factor dependent to percentage of reinforcement
k_r	kern in the roof
k_t	factor dependent to the age of the concrete when post-tensioned
L_d	development length of stirrups
M	moment

M_{neg}	negative moment (∩)
M_{pos}	positive moment (U)
N	normal force / horizontal force
N_{cables}	number of cables
P	point load / force
P_f	point load in the floor
P_r	point load in the roof
$P_{resultant}$	resultant force / point load
R_X	rotation in x direction
R_z	rotation in z direction
S	the minimum total area for structural concrete
U_Y	translation in Y direction
t	thickness of a structure
W_f	modulus of inertia in the floor
W_r	modulus of inertia in the roof
Z_f	distance from the post-tensioned cables in the floor to the tunnel's center of gravity
Z_r	distance from the post-tensioned cables in the roof to the tunnel's center of gravity
%Fa	percentage of relaxation occurs after 1000 hours
$\%F_{pu}$	percentage of stress happens on the cable

Element	a unit consists of several segments
HWL	High Water Level
LWL	Low Water Level
NAP	Normaal Amsterdams Peil/Amsterdam Ordnance Datum (AOD)
NEN	Dutch standard
Segment	a part of an element
SKSNI	Indonesia standard
SLS	Service Limit State
ULS	Ultimate Limit State
VDTZ	*Voorgedrukte Trek Zone*